10/049362 06 FEB 2002

FORM PTO-1390 (REV. 12-2001)

U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY 'S DOCKET NUMBER: 30794.61USWO

U S APPLICATION NO (If known, see 37 CFR 1 5): 10/049362

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/US00/23710	29 August 2000 (29.08.00)	3 September 1999 (03.09.99)

TITLE OF INVENTION
TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL MODULATOR

APPLICANT(S) FOR DO/EO/US
Thomas Gordon Beck Mason, Larry A. Coldren, and Gregory Fish

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [ ] This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. [X] The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [ ] is attached hereto (required only if not communicated by the International Bureau).
   b. [ ] has been communicated by the International Bureau.
   c. [X] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [ ] An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. [ ] is attached hereto.
   b. [ ] has been previously submitted under 35 U.S.C. 154(d)(4).
7. [X] Amendments to the claims of the International Aplication under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are attached hereto (required only if not communicated by the International Bureau).
   b. [ ] have been communicated by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [X] have not been made and will not be made.
8. [ ] An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. [ ] An English lanugage translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. [ ] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [ ] A FIRST preliminary amendment.
14. [ ] A SECOND or SUBSEQUENT preliminary amendment.
15. [ ] A substitute specification
16. [ ] A change of power of attorney and/or address letter.
17. [ ] A computer-readable form of the sequence listing in accordance with PCT Rule 13ter 2 and 35 U S.C. 1.821 - 1 825
18. [ ] A second copy of the published international application under 35 U.S C. 154(d)(4).
19. [ ] A second copy of the English language translation of the international application under 35 U S C 154(d)(4)
20. [XX] Other items or information
   a. Verified Statement Claiming Small Entity Status - by Agility Communications, Inc.
   b. Verified Statement Claiming Small Entity Status - by The Regents of the University of California

06 FEB 2002

U.S. APPLICATION NO (if known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
	PCT/US00/23710	30794.61USWO

				CALCULATIONS	PTO USE ONLY
21. [XX] The following fees are submitted **BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):** Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO .. **$1040.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO . **$890.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO . **$740.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) .... **$710.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**					
ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 100.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(c)).				$	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	$	
Total claims	26 - 20 =	6	x **$18.00**	$ 108.00	
Independent claims	3 - 3 =		x **$84.00**	$	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ **$280.00**	$	
TOTAL OF ABOVE CALCULATIONS =				$ 208.00	
[XX] Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2. +				$ 104.00	
SUBTOTAL =				$ 104.00	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				$	
TOTAL NATIONAL FEE =				$ 104.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$	
TOTAL FEES ENCLOSED =				$ 104.00	
				Amount to be refunded:	$
				charged:	$

a. [ ] A check in the amount of $ ______________ to cover the above fees is enclosed

b. [ ] Please charge my Deposit Account No ______________ in the amount of $ __________ to cover the above fees A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No 50-0494 A duplicate copy of this sheet is enclosed

d. [XX] Fees are to be charged to a credit card **WARNING:** Information on this form may become public **Credit card information should not be included on this form** Provide credit card information and authorization on PTO-2038

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO

George H. Gates
GATES & COOPER LLP
6701 Center Drive West, Suite 1050
Los Angeles, CA 90045

SIGNATURE

George H. Gates
NAME

33,500
REGISTRATION NUMBER

PTO/PCT Rec'd 06 FEB 2002

10/049362

TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL MODULATOR

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority under 35 U.S.C. § 119(e) of United States Provisional Patent Application Serial No. 60/152,432, filed September 3, 1999, by Thomas G.B. Mason, Larry A. Coldren, and Gregory Fish, entitled "TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL MODULATOR," which application is incorporated by reference herein.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

This invention was made with Government support under Grant No. N00014-96-1-6014, awarded by the Office of Naval Research. The Government has certain rights in this invention.

BACKGROUND OF THE INVENTION

1. Field of the Invention.

This invention relates in general to semiconductor lasers, and in particular to a tunable laser source with integrated optical modulator.

2. Description of the Related Art.

Modern day usage of optical components and lasers has made communications and data transfer more efficient and more cost effective. The use of semiconductor lasers has made the fabrication and packaging of optical sources more cost effective, as well as reducing the size of the overall device.

However, the requirements for communications and data transfer systems have also increased. Widely tunable lasers are essential components for a wide variety of wavelength-division multiplexing (WDM) and packet switching network architectures. They can be used as replacement sources in long haul dense WDM communication systems or for wavelength routing in access networks. They are also important devices for next generation phased array radar systems that use true-time delay beam steering.

In order to achieve a wide tuning range, these devices require fairly large passive tuning elements. This makes the devices four to five times larger than conventional fixed wavelength lasers. However, having this large amount of passive material in a laser cavity reduces the speed with which they can be turned on and off by direct current modulation. Moreover, the rate at which they are able to transmit data is limited, making them unsuitable for high bandwidth applications.

There are two other factors that make it difficult to use these devices to transmit data. The wavelength in a sampled grating distributed Bragg reflector (SGDBR) laser is controlled by aligning a pair of reflection peaks in two mirrors with an optical cavity mode. When a gain current is modulated over a wide range of currents, it can disturb this alignment, resulting in mode instability within the device, which is highly undesirable for data transmission. To prevent this mode instability, such devices can only be modulated over a narrow range of output powers, which introduces a significant extinction ratio penalty to their data transmission performance.

The other problem with directly modulating a laser is frequency chirp, which is the shift in the laser oscillation frequency that occurs when the output power level is changed. This is undesirable in transmission systems, since frequency chirp causes pulse spreading, which limits the maximum distance over which data can be sent over an optical fiber or other dispersive medium.

The three most successful types of widely tunable lasers are the super structure grating distributed Bragg reflector laser (SSGDBR), the grating assisted codirectional coupler with sampled grating reflector laser (GCSR), and the sampled grating DBR laser (SGDBR). All of these devices are capable of continuous tuning ranges greater than 40 nm. However, SGDBR lasers and other widely tunable designs have long active sections and fairly large optical cavities that limit their direct modulation bandwidth to between 3 and 4 GHz. This enables them to be used in OC-48 data transmission systems under direct modulation, if some wavelength chirping can be tolerated. However, this bandwidth is insufficient for use in most phased array radar systems or in OC-192 data transmission networks operating at 10 Gb/s.

In these applications, external modulators are frequently used to apply a radio frequency (RF) signal or data to the optical carrier. Even for long-haul OC-48 systems, external modulators are frequently used to minimize frequency chirp. However, external

modulators add significant cost and complexity to the optical assembly which can be prohibitive in systems that require a large number of tunable lasers and modulators. For this reason, it is desirable to monolithically integrate a high speed modulator with a tunable laser on as a single semiconductor device.

SUMMARY OF THE INVENTION

To minimize the limitations in the prior art described above, and to minimize other limitations that will become apparent upon reading and understanding the present specification, the present invention discloses a device, method, and article of manufacture related to a tunable laser source with integrated optical modulator. The tunable laser source is a widely tunable semiconductor laser that is comprised of an active region on top of a thick, low bandgap, waveguide layer, wherein both the waveguide layer and the active region are fabricated between a p-doped region and an n-doped region. An electro-absorption modulator is integrated into the semiconductor laser, wherein the electro-absorption modulator shares the waveguide layer with the semiconductor laser.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIG. 1 is a perspective view that illustrates the structure of a widely tunable semiconductor laser with an integrated electro-absorption modulator according to a preferred embodiment of the present invention;

FIG. 2 illustrates a cross-section of the laser and modulator according to the preferred embodiment of the present invention;

FIGS. 3A and 3B are charts that illustrate the tuning curves for wide wavelength tuning according to the preferred embodiment of the present invention;

FIGS. 4A, 4B, and 4C illustrate the Franz-Keldysh effect in the modulator according to the preferred embodiment of the present invention;

FIG. 5 is a chart that illustrates the response curves for initial tests of the integrated laser and modulator device over a 50 nm tuning range according to the preferred embodiment of the present invention; and

FIGS. 6A and 6B are flowcharts illustrating the steps used in the fabrication process according to the preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

In the following description of the preferred embodiment, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration a specific embodiment in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

Overview

The present invention provides a simple and effective method for creating a tunable laser with an integrated optical modulator that can be fabricated on a single semiconductor chip. The laser can be rapidly tuned over a wide range of wavelengths, thereby enabling it to be used in a variety of applications from wavelength division multiplexed fiber optic communications to phased array radar. Integrating the modulator with the laser provides a highly desirable method for modulating the intensity of the output from the laser without perturbing its mode stability or introducing high levels of frequency chirp. It also enables much higher modulation frequencies to be reached than with the laser alone.

Device Structure

FIG. 1 is a perspective view that illustrates the structure of a widely tunable semiconductor laser with an integrated electro-absorption modulator according to a preferred embodiment of the present invention. The laser 10 is a four-section buried-ridge sampled-grating distributed Bragg reflector (SGDBR) laser. The four separate sections of the laser 10 comprise tuning sections and include: a sampled grating back mirror section 12, a phase control section 14, a gain section 16, and a sampled grating front mirror section 18. An electro-absorption (EA) modulator 20 shares a common waveguide 22 with the back mirror section 12, phase control section 14, gain section 16, and front mirror section 18 of the laser 10, wherein the waveguide 22 is designed to provide high index tuning efficiency in the laser 10 and good reverse bias extinction in

the modulator 20. Generally, a bias voltage is connected to the top of the device and a ground is connected to the bottom. When the bias voltage on the gain section 16 is above a lasing threshold, laser 10 output is produced.

FIG. 2 illustrates a cross-section of the integrated laser 10 and modulator 20 device according to the preferred embodiment of the present invention. The device is comprised of an n-doped region 24, a thick, low bandgap waveguide layer 26 (to form the waveguide 22 shown in FIG. 1), an anti-reflective coating 28, a stop etch layer 30, an active region 32, a p-doped region 34, a p+ contact layer 36, and metal contacts 38.

N-doped region 24 and p-doped region 34 are typically of different dopant types. Although indium phosphide (InP) is used in the preferred embodiment, the doped regions 24 and 34, and active region 32 can be of any laser producing material. Moreover, the relative positions of the n-doped region 24 and p-doped region 34 can be reversed without departing from the scope of the invention.

A lateral waveguide 22 is formed by laterally patterning the waveguide layer 26 or layer 34 above it into a stripe geometry. A key design element of the present invention is that a single common waveguide 22 is used for the tuning sections 12, 14, 16, and 18 in the laser 10, and for the modulator 20. The lateral waveguide 22 structure may be formed as a buried ridge, or other type of lateral waveguide 22 structure, such as a simple ridge.

The p-doped region 34 also includes proton implants 40 above and beside the waveguide 22 that are blocking junctions that act as isolators to block lateral current leakage in the laser 10, as well as to provide isolation between sections in the laser 10, to reduce parasitic junction capacitance of the modulator 20, and to provide isolation from the modulator 20.

The active region 32 includes offset multiple quantum wells (MQW) that provide the laser 10 output. When an electrical current passes from the p-doped region 34 to the n-doped region 24 through the active region 32, a laser 10 light output is produced from the MQW. The active region 32 and the waveguide layer 26 are separated by the stop etch layer 30 to enable the active region 32 to be removed with a selective wet etchant during fabrication.

Both the back and front mirror sections 12 and 18 comprise a set of periodically sampled gratings that are etched into the waveguide layer 26 with a period 42. Gratings

of this type act as wavelength selective reflectors, wherein one or more specified sampling periods 42 will provide a partial reflection at periodic wavelength spacings of an optical signal carried by the waveguide 22. The laser 10 can be rapidly tuned over a wide wavelength range by proper adjustment of control currents for the mirror sections 12 and 18, for example, as described in U.S. Patent No. 4,896,325, which is incorporated by reference herein.

The anti-reflective coating 28 is applied to each end of the device after the device is cleaved out of the wafer.

Tuning Curves

FIGS. 3A and 3B are charts that illustrate the tuning curves for wide wavelength tuning according to the preferred embodiment of the present invention. In FIG. 3A, the X-axis is the back mirror 12 current (mA) and the Y-axis highest wavelength (nm). In FIG. 3B, the X-axis is the front mirror 18 current (mA) and the Y-axis highest wavelength (nm).

As shown in FIGS. 3A and 3B, the principal advantage of this laser 10 is that it can be rapidly tuned over a wide wavelength range by proper adjustment of control currents for the mirrors 12 and 18. This is a highly desirable feature that makes the device of the present invention useful for current and next generation fiber networks.

Franz-Keldysh Effect

FIGS. 4A, 4B, and 4C illustrate the Franz-Keldysh effect in the modulator 20 according to the preferred embodiment of the present invention. In these diagrams, E_1 is the energy level of the valence band (E_v), E_2 is the energy level of the conduction band (E_c), Δ E is the bandgap between E_1 and E_2, and Δ x is the thickness of the waveguide layer 26.

In the present invention, performance is optimized by using a thick, low bandgap waveguide layer 26. This provides good index tuning efficiency in the mirror sections 12 and 18, and a reasonable extinction ratio and chirp parameter in the modulator 20.

The operation of the modulator 20 is based on either the Franz-Keldysh effect in a bulk semiconductor waveguide 22 or the quantum confined Stark effect in a MQW . When a strong electric field is applied to the waveguide 22, the band edge of the material

is shifted to lower energies allowing it to absorb the output light of the laser 10, as shown in FIGS. 4A, 4B, and 4C. This technique allows very rapid modulation of the laser 10 with minimal wavelength chirping. Under proper conditions, this can produce sufficient optical loss to extinguish the output light intensity by more than 20 dB, even over a wide wavelength range.

For narrower ranges of operation, the modulator 20 could comprise an MQW modulator grown into the center of a higher bandgap waveguide layer 26. This would provide less efficient tuning in the laser 10, but would allow for lower voltage operation in the modulator 20, since the bandgap detuning can be reduced due to the sharper absorption edge of the MQW structure.

Response Curves

FIG. 5 is a chart that illustrates the response curves for initial tests of the integrated laser 10 and modulator 20 device over a 50 nm tuning range according to the preferred embodiment of the present invention. These initial tests of the buried heterostructure electro-absorption modulator 20 integrated with a sampled grating distributed Bragg reflector laser 10 were conducted to demonstrate the operation and benefits of the present invention. In these tests, a 400 nanometer thick waveguide 22 with a bandgap wavelength of 1.4 microns was used. The laser 10 had a tuning range of more than 47 nanometers. The modulator 20 was able to produce more than 26 dB over this entire tuning range with only a 4 volt bias.

Fabrication Process

FIGS. 6A and 6B are flowcharts illustrating the steps used in the fabrication process according to the preferred embodiment of the present invention. FIG. 6A shows the steps used when a lateral waveguide is being formed as a simple ridge, while FIG. 6B shows the steps used for other types of lateral waveguiding structures, such as a buried ridge stripe.

Referring to FIG. 6A, Block 44 represents a first growth step, with an n-InP buffer layer 24, Q-waveguide layer 26, stop etch layer 30, active MQW region 32, and small portion of the p-InP cladding layer 34 being grown.

Block 46 represents the patterning and selectively etching off of the thin top p-InP cladding layer 34 and active regions 32 down to the stop-etch layer 30, everywhere except in the gain section 16 of the laser 10.

Block 48 represents the patterning and etching of one or more sets of periodically sampled gratings with period 42 in the mirror sections 12 and 18.

For the simple ridge, Block 50 represents the second growth that completes the vertical structure growth of the p-InP cladding layer 34 and the p+ contact layer 36 beneath the contacts 38.

Block 52 represents the proton implants 40 being performed to isolate sections of the laser 10, and to provide isolation between the modulator 20 and the laser 10.

Block 54 patterns the contacts 38, removes the p+ contact layer 36 therebetween by etching, and metalizes the contacts 38.

Block 56 etches a ridge waveguide 22 stripe down to the active region 32 or the waveguide layer 26.

Block 58 cleaves the laser 10 and modulator 20 device out of the wafer, and then applies antireflective (AR) coatings 28 on each end of the device.

Referring to FIG. 6B, Block 60 represents a first growth step, with an n-InP buffer layer 24, Q-waveguide layer 26, stop etch layer 30, active MQW region 32, and thin p-InP cladding layer 34 being grown.

Block 62 represents the patterning and selectively etching off of the thin top p-InP cladding layer 34 and active regions 32 down to the stop-etch layer 30, everywhere except in the gain section 16 of the laser 10.

Block 64 represents the patterning and etching of one or more sets of periodically sampled gratings of period 42 in the mirror sections 12 and 18 that are coupled to the active region 32.

For the buried ridge, Block 66 represents the second growth step, which comprises only a thin additional growth of the p-InP cladding layer 34 to cover the periodically sampled 42 gratings in the mirror sections 12 and 18.

Block 68 represents a patterning and etching of the buried ridge waveguide 22 stripe, which is etched laterally to beneath the waveguide layer 26.

Block 70 represents a third growth of the p-InP cladding layer 34 and the p+ contact layer 36.

Block 72 represents proton implants 40 being performed to isolate sections of the laser 10, and between the modulator 20 and the laser, as well as to limit lateral current leakage.

Block 74 patterns the contacts 38, removes the p+ contact layer 36 therebetween by etching, and metalizes the contacts 38.

Block 76 cleaves the laser 10 and modulator 20 device out of the wafer, and then applies antireflective (AR) coatings 28 on each end of the device.

Conclusion

This concludes the description of the preferred embodiment of the invention.

In summary, the present invention discloses a device, method, and article of manufacture related to a tunable laser source with integrated optical modulator. The tunable laser source is a widely tunable semiconductor laser that is comprised of an active region on top of a thick, low bandgap, waveguide layer, wherein both the waveguide layer and the active region are fabricated between a p-doped region and an n-doped region. An electro-absorption modulator is integrated into the semiconductor laser, wherein the electro-absorption modulator shares the waveguide layer with the semiconductor laser.

The foregoing description of the preferred embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

WHAT IS CLAIMED IS:

1. A tunable laser source comprising

a widely tunable semiconductor laser comprised of an active region on top of a thick, low bandgap, waveguide layer, wherein both the waveguide layer and the active region are fabricated between a p-doped region and an n-doped region; and

an electro-absorption modulator integrated into the semiconductor laser, wherein the electro-absorption modulator shares the waveguide layer with the semiconductor laser.

2. The tunable laser source of claim 1, wherein the semiconductor laser includes a sampled grating back mirror, a phase control section, a gain section, and a sampled grating front mirror.

3. The tunable laser source of claim 2, wherein the waveguide layer is a single common waveguide layer used for the sampled grating back mirror, phase control section, gain section, sampled grating front mirror, and modulator.

4. The tunable laser source of claim 1, wherein the waveguide layer is designed to provide high index tuning efficiency in the laser and good reverse bias extinction in the modulator.

5. The tunable laser source of claim 1, wherein the waveguide is a buried heterostructure waveguide that includes offset multiple quantum wells (MQW) that provide the laser's output.

6. The tunable laser source of claim 1, wherein the waveguide is a ridge waveguide that includes offset multiple quantum wells (MQW) that provide the laser's output.

7. The tunable laser source of claim 1, wherein the waveguide layer includes a blocking junction that blocks lateral current leakage in the laser and reduces parasitic junction capacitance of the modulator.

8. The tunable laser source of claim 1, wherein the semiconductor laser is rapidly tuned over a wide wavelength range by proper adjustment of control currents for the mirrors.

9. A method for fabricating a tunable laser with an integrated modulator, comprising:

(a) performing a first growth step, wherein a buffer layer, a waveguide layer, a stop etch layer, an active region, and a terminating layer are grown on a semiconductor wafer;

(b) patterning and etching the terminating layer and active region down to the stop-etch layer, everywhere except in a gain section of the laser;

(c) patterning and etching of one or more sets of periodically sampled gratings in one or more mirror sections of the laser;

(d) performing a second growth step that completes a vertical structure growth of the terminating layer and a contact layer beneath one or more contacts of the laser;

(e) isolating sections of the laser from one another, and between the modulator and the laser;

(f) patterning the contacts of the laser, removing the contact layer therebetween by etching, and metalizing the contacts;

(g) patterning and etching a ridge waveguide stripe down to either the active region or the waveguide layer and;

(h) cleaving the device out of the wafer, and then applying an antireflective coating on at least one end of the device.

10. The method of claim 9, wherein the laser includes a sampled grating back mirror, a phase control section, a gain section, and a sampled grating front mirror.

11. The method of claim 9, wherein the waveguide layer is a single common waveguide layer used for the sampled grating back mirror, phase control section, gain section, sampled grating front mirror, and modulator.

12. The method of claim 9, wherein the waveguide layer is designed to provide high index tuning efficiency in the laser and good reverse bias extinction in the modulator.

13. The method of claim 9, wherein the waveguide is a buried heterostructure waveguide that includes offset multiple quantum wells (MQW) that provide the laser's output.

14. The method of claim 9, wherein the waveguide is a ridge waveguide that includes offset multiple quantum wells (MQW) that provide the laser's output.

15. The method of claim 9, wherein the waveguide layer includes one or more blocking junctions that blocks lateral current leakage in the laser and reduces parasitic junction capacitance of the modulator.

16. The method of claim 9, wherein the laser is rapidly tunable over a wide wavelength range by proper adjustment of control currents for its mirrors.

17. An article of manufacture comprising a tunable laser with integrated optical modulator fabricated according to the method of claim 9.

18. A method for fabricating a tunable laser with an integrated modulator, comprising:

(a) performing a first growth step, wherein a buffer layer, a waveguide layer, a stop etch layer, an active region, and a cladding layer are grown on a semiconductor wafer;

(b) patterning and selectively etching off of the cladding layer and active region down to the stop-etch layer, everywhere except in a gain section;

(c) patterning and etching of one or more sets of periodically sampled gratings in one or more mirror sections of the laser;

(d) performing a second growth step, wherein an additional growth of the cladding layer is grown to cover one or more periodically sampled gratings in the mirror sections;

(e) patterning and etching a buried ridge waveguide stripe, wherein the waveguide strip is etched laterally to beneath the waveguide layer;

(f) performing a third growth step that completes a vertical structure growth of the terminating layer and a contact layer beneath one or more contacts of the laser;

(g) isolating sections of the laser from one another, and between the modulator and the laser;

(h) patterning the contacts of the laser, removing the contact layer therebetween by etching, and metalizing the contacts;

(i) cleaving the device out of the wafer, and then applying antireflective coatings on at least one end of the device.

19. The method of claim 18, wherein the laser includes a sampled grating back mirror, a phase control section, a gain section, and a sampled grating front mirror.

20. The method of claim 18, wherein the waveguide layer is a single common waveguide layer used for the sampled grating back mirror, phase control section, gain section, sampled grating front mirror, and modulator.

21. The method of claim 18, wherein the waveguide layer is designed to provide high index tuning efficiency in the laser and good reverse bias extinction in the modulator.

22. The method of claim 18, wherein the waveguide is a buried heterostructure waveguide that includes offset multiple quantum wells (MQW) that provide the laser's output.

23. The method of claim 18, wherein the waveguide is a ridge waveguide that includes offset multiple quantum wells (MQW) that provide the laser's output.

24. The method of claim 18, wherein the waveguide layer includes one or more blocking junctions that blocks lateral current leakage in the laser and reduces parasitic junction capacitance of the modulator.

25. The method of claim 18, wherein the laser is rapidly tunable over a wide wavelength range by proper adjustment of control currents for its mirrors.

26. An article of manufacture comprising a tunable laser with integrated optical modulator fabricated according to the method of claim 18.

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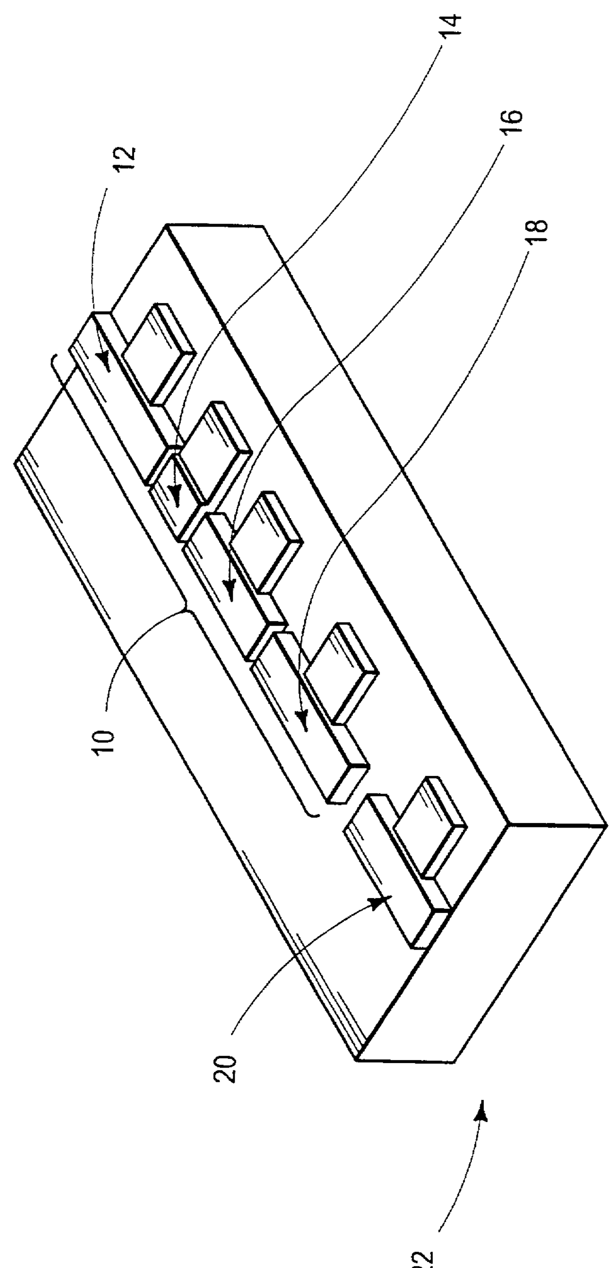

FIG. 1

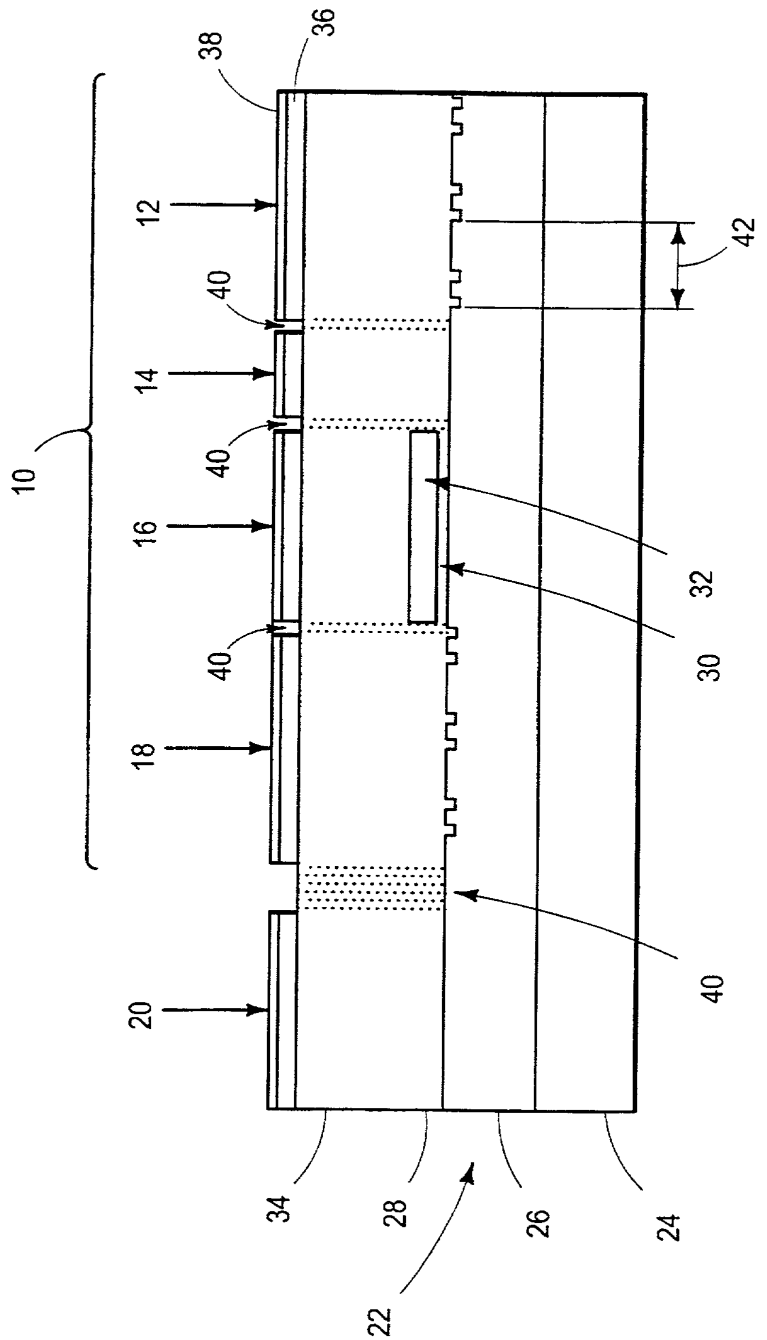

FIG. 2

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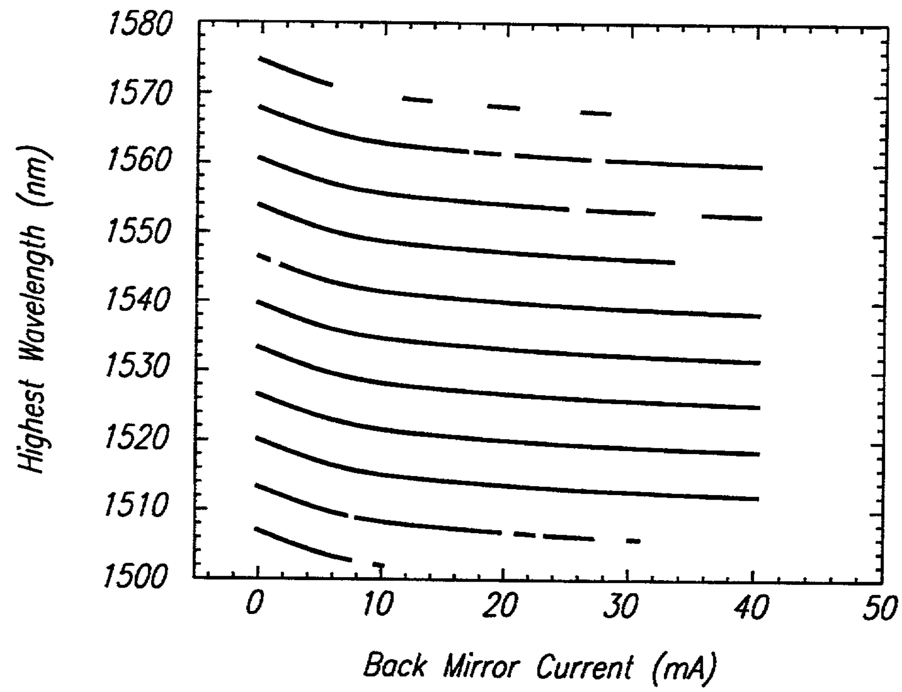


FIG. 3A

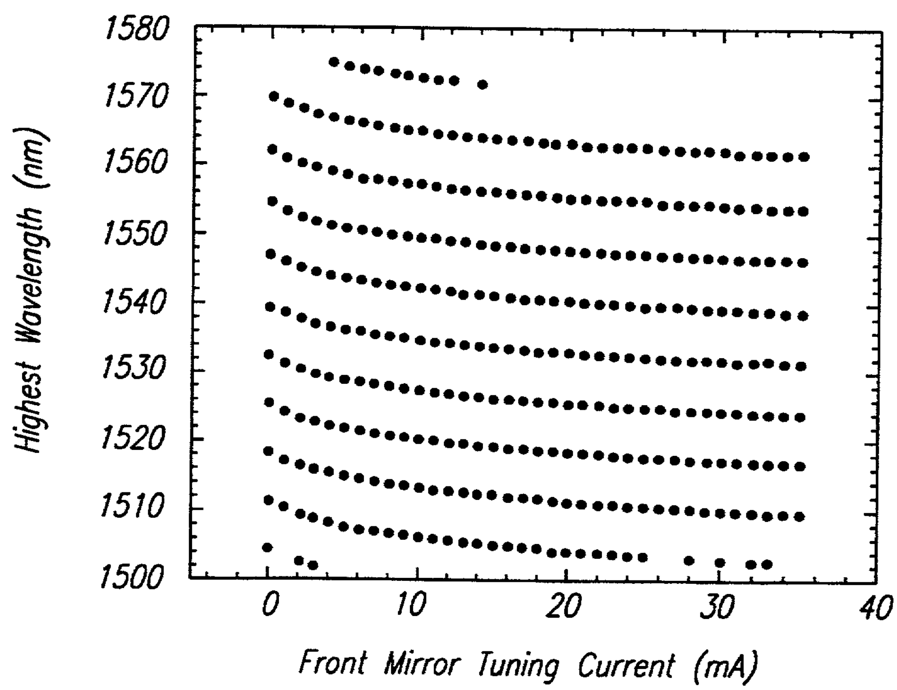


FIG. 3B

FIG. 4A

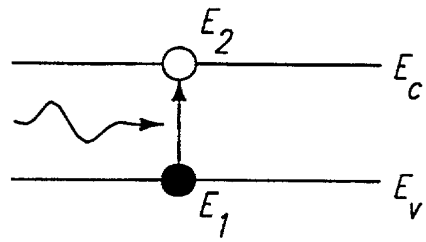


FIG. 4B

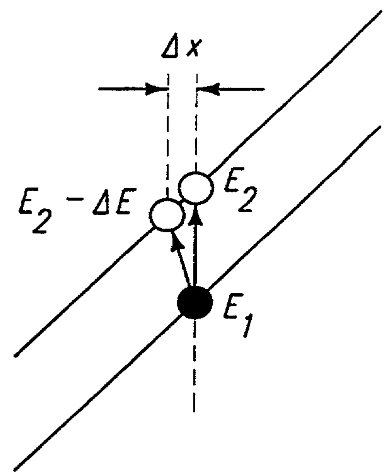
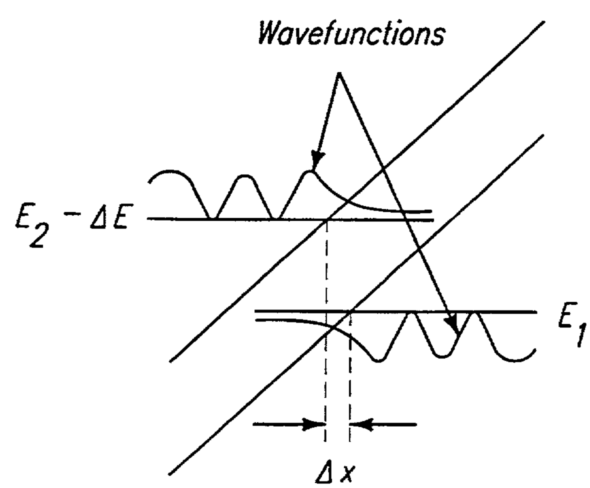


FIG. 4C



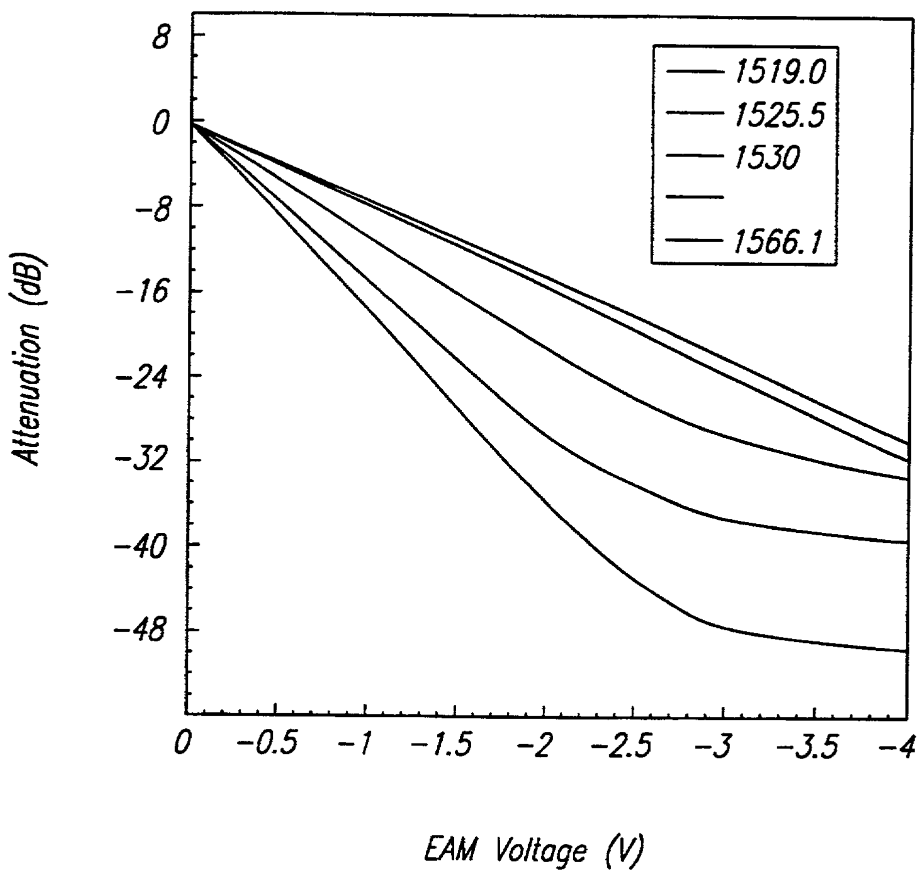

8
0
-8
-16
-24
-32
-40
-48
Attenuation (dB)
1519.0
1525.5
1530
1566.1
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
EAM Voltage (V)

FIG. 5

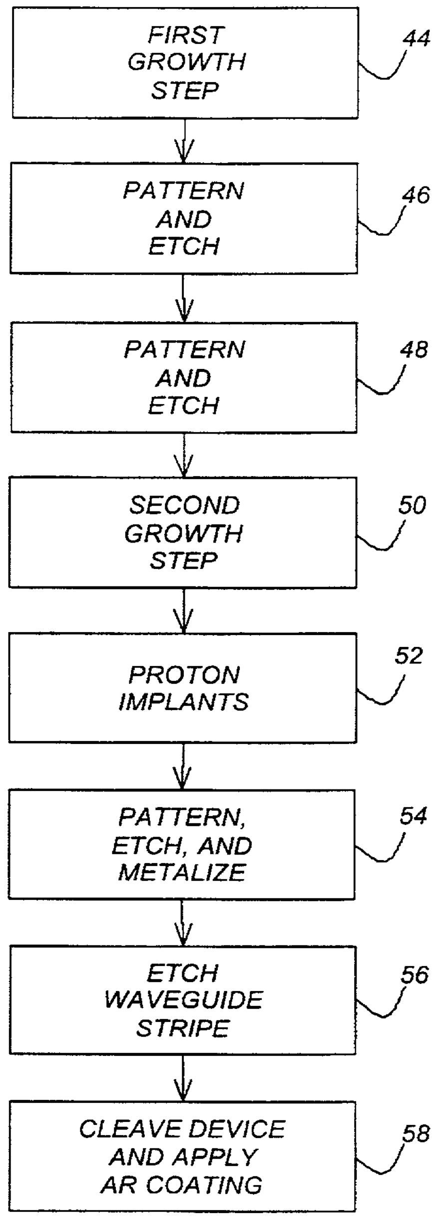

FIRST GROWTH STEP
44
PATTERN AND ETCH
46
PATTERN AND ETCH
48
SECOND GROWTH STEP
50
PROTON IMPLANTS
52
PATTERN, ETCH, AND METALIZE
54
ETCH WAVEGUIDE STRIPE
56
CLEAVE DEVICE AND APPLY AR COATING
58

FIG. 6A

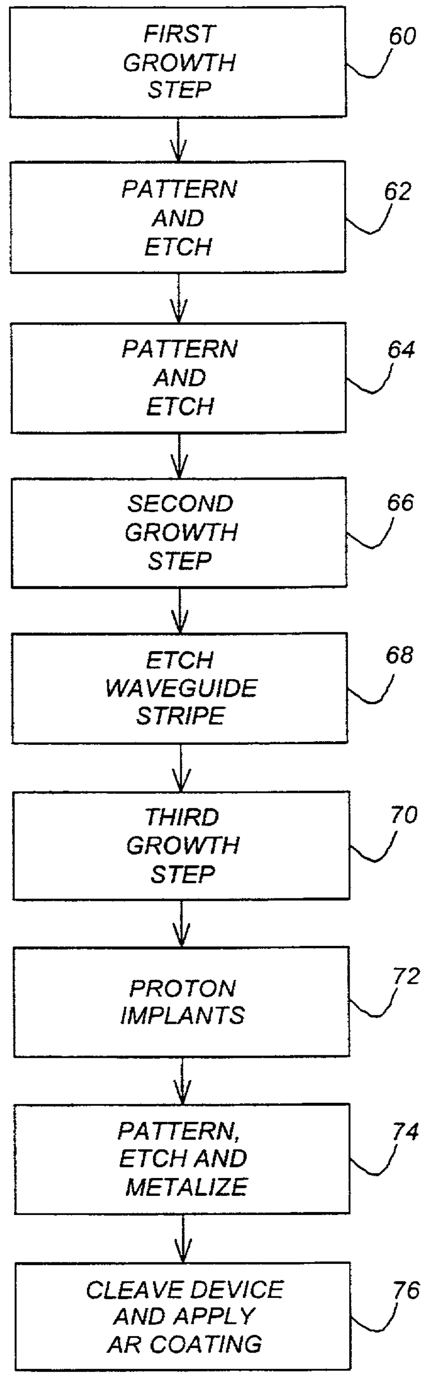

FIRST GROWTH STEP
60
PATTERN AND ETCH
62
PATTERN AND ETCH
64
SECOND GROWTH STEP
66
ETCH WAVEGUIDE STRIPE
68
THIRD GROWTH STEP
70
PROTON IMPLANTS
72
PATTERN, ETCH AND METALIZE
74
CLEAVE DEVICE AND APPLY AR COATING
76

FIG. 6B

GATES & COOPER LLP

United States Patent Application

COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor I hereby declare that: my residence, post office address and citizenship are as stated below next to my name, that

I verily believe I am the original, first and sole inventor (if only one name is listed below) or a joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL MODULATOR

The specification of which

a. ☐ is attached hereto.

b. ☒ was filed on **August 29, 2000** as PCT International Application Number **PCT/US00/23710**, which I have reviewed and for which I solicit a United States patent

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1 56 (attached hereto).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate or any PCT application having a filing date before that of the application on the basis of which priority is claimed:

a. ☒ no such applications have been filed
b. ☐ such applications have been filed as follows:

FOREIGN APPLICATION(S), IF ANY, CLAIMING PRIORITY UNDER 35 USC § 119			
COUNTRY	**APPLICATION NUMBER**	**DATE OF FILING (day, month, year)**	**DATE OF ISSUE (day, month, year)**
OTHER FOREIGN APPLICATION(S), IF ANY, FILED BEFORE THE PRIORITY APPLICATION(S)			
COUNTRY	**APPLICATION NUMBER**	**DATE OF FILING (day, month, year)**	**DATE OF ISSUE (day, month, year)**

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s), or 365(c) of any PCT international application(s) designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1 56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. PARENT APPLICATION OR PCT PARENT NUMBER	DATE OF FILING (day, month, year)	STATUS (patented, pending, abandoned)

I hereby claim the benefit under Title 35, United States Code § 119(e) of any United States provisional application(s) listed below:

U.S. PROVISIONAL APPLICATION NUMBER	DATE OF FILING (Day, Month, Year)
60/152,432	03 SEP 99

I hereby appoint the following attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith:

George H. Gates	Registration No. 33,500
Victor G. Cooper	Registration No. 39,641
Karen S. Canady	Registration No. 39,927
William J. Wood	Registration No. 42,236
Jason S. Feldmar	Registration No. 39,187
Bradley K. Lortz	Registration No. 45,472

I hereby authorize them to act and rely on instructions from and communicate directly with the person/assignee/attorney/firm/ organization who/which first sends/sent this case to them and by whom/which I hereby declare that I have consented after full disclosure to be represented unless/until I instruct Gates & Cooper LLP to the contrary.

Please direct all correspondence in this case to the firm of Gates & Cooper LLP at the address indicated below:

CUSTOMER NUMBER 22462
Gates & Cooper LLP
Howard Hughes Center
6701 Center Drive West, Suite 1050
Los Angeles, CA 90045
(310) 641-8797

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

(1)	Full Name Of Inventor	Family Name MASON	First Given Name Thomas	Second Given Name Gordon Beck
	Residence & Citizenship	City Bethlehem	State or Foreign Country Pennsylvania	Country of Citizenship CANADA
	Post Office Address	Post Office Address 1680 Cambridge Court	City Bethlehem	State & Zip Code/Country Pennsylvania 18015 / U.S.A.
Signature of Inventor(1):		Thomas Gordon Beck Mason		Date: 01/02/02

(30794 61USWO)

(2)	Full Name Of Inventor	Family Name COLDREN	First Given Name Larry	Second Given Name A.
	Residence & Citizenship	City Santa Barbara	State or Foreign Country California CA	Country of Citizenship U.S.A.
	Post Office Address	Post Office Address 4665 Via Vistosa	City Santa Barbara	State & Zip Code/Country California 93110 / U.S.A.
Signature of Inventor(2):				Date: 2/04/02
(3)	Full Name Of Inventor	Family Name FISH	First Given Name Gregory	Second Given Name
	Residence & Citizenship	City Santa Barbara	State or Foreign Country California CA	Country of Citizenship U.S.A
	Post Office Address	Post Office Address 5049 Via Lara Lane	City Santa Barbara	State & Zip Code/Country California 93111 / U.S.A
Signature of Inventor(3):				Date: 2/04/02

§ 1.56 Duty to disclose information material to patentability.

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is canceled or withdrawn from consideration, or the application becomes abandoned Information material to the patentability of a claim that is canceled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§ 1.97(b)-(d) and 1 98 However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct The Office encourages applicants to carefully examine

(1) prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

(1) it establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim, or

(2) it refutes, or is inconsistent with, a position the applicant takes in

(i) opposing an argument of unpatentability relied on by the Office, or

(ii) asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) each inventor named in the application:

(2) each attorney or agent who prepares or prosecutes the application, and

(3) every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.

SMALL BUSINESS

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS
(37 C.F.R. 1.9(f) AND 1.27(c)) – SMALL BUSINESS CONCERN

I hereby declare that I am:

☒ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF CONCERN: **Agility Communications, Inc.**
ADDRESS OF CONCERN: **421 Pine Avenue**
Santa Barbara, California 93117

I hereby declare that the above-identified small business concern qualifies as a small business as defined in 13 C.F.R. 121.801-805, and reproduced in 37 C.F.R. 1.9(d) for purposes of paying reduced fees under Section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement. (1) the number of employees of the concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention, entitled **TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL MODULATOR** by inventor(s) **Thomas Gordon Beck Mason**, **Larry A. Coldren**, and **Gregory Fish** described in:

☒ International Application No. **PCT/US00/23710**, filed in the United States Receiving Office on **August 29, 2000**.

If the rights held by the above-identified small business concern are not exclusive, each individual, concern or organization having rights to the invention listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as an independent inventor under 37b C.F.R. 1.9(c) or by any concern which would not qualify as a small business concern under 37 C.F.R. 1.9(d) or a nonprofit organization under 37 C.F.R. 1.9(e) *NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 C.F.R. 1.27)

NAME The Regents of the University of California
ADDRESS 1111 Franklin Street, 12th Floor, Oakland, California 94607-5200
☐ INDIVIDUAL ☐ SMALL BUSINESS ☒ NONPROFIT ORGANIZATION

NAME ______
ADDRESS ______
☐ INDIVIDUAL ☐ SMALL BUSINESS ☐ NONPROFIT ORGANIZATION

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as small entity is no longer appropriate. (37 C.F.R. 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereof, or any patent to which this verified statement is directed.

NAME: Ron Nelson
TITLE: President and CEO
ADDRESS: 421 Pine Avenue
Santa Barbara, California 93117

SIGNATURE: ______ DATE: 2/4/02

NONPROFIT ORGANIZATION

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS
(37 C.F.R. 1.9(e) AND 1.27(d)) – NONPROFIT ORGANIZATION

I hereby declare that I am an official empowered to act on behalf of the nonprofit organization identified below:

NAME OF ORGANIZATION: The Regents of the University of California
ADDRESS OF ORGANIZATION: 1111 Franklin Street, 12th Floor
Oakland, California 94607

TYPE OF NONPROFIT ORGANIZATION:

a) ☒ UNIVERSITY OR OTHER INSTITUTION OF HIGHER EDUCATION

b) ☐ TAX EXEMPT UNDER INTERNAL REVENUE SERVICE CODE (26 U.S.C. 501(a) and 501(c)(3))

c) ☐ NONPROFIT SCIENTIFIC OR EDUCATIONAL UNDER STATUTE OF STATE OF THE UNITED STATES OF AMERICA
(NAME OF STATE____________________)
(CITATION OF STATUTE____________________)

d) ☐ WOULD QUALIFY AS TAX EXEMPT UNDER INTERNAL REVENUE SERVICE CODE (26 U.S.C. 501(a) and 501(c)(3)) IF LOCATED IN THE UNITED STATES OF AMERICA

e) ☐ WOULD QUALIFY AS NONPROFIT SCIENTIFIC OR EDUCATIONAL UNDER STATUTE OF STATE OF THE UNITED STATES OF AMERICA IF LOCATED IN THE UNITED STATES OF AMERICA
(NAME OF STATE____________________)
(NAME OF STATUTE____________________)

I hereby declare that the nonprofit organization identified above qualifies as a nonprofit organization as defined in 37 C.F.R. 1.9(e) for purposes of paying reduced fees under Section 41(a) and (b) of Title 35, United States Code, in regard to the invention, entitled: **TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL MODULATOR** by inventor(s) Thomas Gordon Beck Mason, Larry A. Coldren, and Gregory Fish described in:

☒ International Application No. PCT/US00/23710, filed in the United States Receiving Office on August 29, 2000.

I hereby declare that rights under contract or law have been conveyed to and remain with the nonprofit organization with regard to the above-identified invention.

If the rights held by the nonprofit organization are not exclusive, each individual, concern or organization having rights to the invention listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as an independent inventor under 37b C.F.R. 1.9(c) or by any concern which would not qualify as a small business concern under 37 C.F.R. 1.9(d) or a nonprofit organization under 37 C.F.R. 1.9(e). ***NOTE:** Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 C.F.R. 1.27)

NAME Agility Communications, Inc.
ADDRESS 421 Pine Avenue, Santa Barbara, California 93117
☐ INDIVIDUAL ☒ SMALL BUSINESS ☐ NONPROFIT ORGANIZATION

NAME ____________________
ADDRESS ____________________
☐ INDIVIDUAL ☐ SMALL BUSINESS ☐ NONPROFIT ORGANIZATION

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as small entity is no longer appropriate. (37 C.F.R. 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both under Section 1001 of Title

18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereof, or any patent to which this verified statement is directed.

NAME: Oren Livne
TITLE. Licensing Officer

ADDRESS: 1111 Franklin Street, 5th Floor
Oakland, California 94607-5200

SIGNATURE:
DATE: 2/4/02